Research

The challenges of acoustic comfort in outdoor private study areas: campus planning and design in universities

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Abstract
The evaluation of outdoor study environment on University Campuses within tropical regions reveals significant deficiencies in acoustic comfort, potentially impairing cognitive performance among students. This study specifically analyzes the acoustic condition of outdoor study areas (*vimbwete*) across four Tanzanian Universities: Mbeya University of Science and Technology, the Tanzania Institute of Accountancy, Mzumbe University and Teofilo Kisanji University. Eighty students aged 18 to 24 with a balanced gender distribution from various disciplines were randomly selected to gauge cognitive performance via a reading comprehension assessment conducted in environments exhibiting ambient noise levels of approximately 50 dB(A) and 75 dB(A). Noise mapping techniques were employed to characterize sound levels across the campuses and the study synthesized both qualitative feedback from participants and quantitative acoustic measurements. The finding indicates a significant prevalence of sound pollution that exceed the World Health Organization 2018 recommendations for outdoor learning environments. A negative correlation was observed between elevated noise levels and cognitive performance metrics, highlighting the urgent necessity for improved campus design and acoustic management strategies. This research provides critical insights into enhancing learning conditions in outdoor academic settings considering immediate noise reduction strategies for existing campuses and comprehensive mitigation for future campus development.

Keywords Noise levels · Cognitive performance · Acoustic comfort · Vimbwete · Outdoor learning environment

Abbreviations

dB	Decibel
MU	Mzumbe University
MUST	Mbeya University of Science and Technology
TEKU	Teofilo Kisanji University
REC	Research Ethics Committee
TIA	Tanzania Institute of Accountancy
WHO	World Health Organization

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1 Introduction

Academic campuses are designed to enhance student learning by integrating outdoor and indoor spaces. In Tropical regions, outdoor areas serve as important informal venues for private study supporting formal indoor learning environments [1, 2]. The importance of outdoor spaces in sub-Saharan Africa universities is gaining recognition especially due to the regions climate which enhances outdoor learning. These areas support effective teaching while fostering student engagement and well-being contributing to a well-rounded educational experience [3, 4]. The escalating challenge of noise pollution in outdoor environments significantly impacts the acoustic comfort essential for optimizing student learning outcomes [5]. In Tanzania, many universities have witnessed a rise in the use of informal outdoor study spaces commonly referred to as "*Vimbwete*" [6]. Despite their popularity, *Vimbwete* often go unacknowledged in universities land masterplans resulting in unstructured growth around campuses. This leaves informal study environments exposed to noise pollution from traffic, construction sites, social gatherings and other activities creating a less conductive learning atmosphere [7]. While the majority of existing literature has concentrated on indoor acoustic comfort [2, 8–12], there is a deficiency in research addressing the acoustic challenges faced by students in outdoor study spaces which serve as an extension of indoor learning environments [13–17]. Previous studies on outdoor environmental quality have predominantly emphasized subjective surveys often neglecting the integration of objective metrics such as acoustic measurements [15, 18]. This study aims to address the disconnect between students' subjective perceptions of their outdoor study environments and objective acoustic metrics. By evaluating both the subjective experience of students and the quantifiable acoustic characteristics, it seeks to explore the implications of sound levels and quality on cognitive performance. This integrative approach will provide valuable insights into how varying acoustic environments impact students' comfort and consequently, their academic success in outdoor campus settings [19, 20].

2 Methodology

2.1 Study area

The study was conducted across four university campuses in Mbeya, Tanzania: Mzumbe University (MU), Mbeya University of Science and Technology (MUST), Teofilo Kisanji University (TEKU) and the Tanzania Institute of Accountancy (TIA). These institutions were selected due to their distinct configurations of outdoor private study spaces and varying proximities to the sources of noise, such as highways, construction sites, railways, and car parking facilities. These four campuses experiences various forms and shapes of outdoor private study spaces (see Fig. 1). The

Fig. 1 Types of outdoor private study areas (Vimbwete) across four Universities

majority of the campuses are situated close to high-traffic roadways, while others are found adjacent to railway line linking Tanzania and Zambia, areas marked by industrial activities and informal settlements. This variation enabled an overall assessment of the influence of noise impacts on academic environments, as supported by earlier research on urban educational surroundings [21, 22].

2.2 Noise monitoring

The noise levels were recorded using a calibrated sound level meter to record dB(A), A-weighted decibels to correspond to human auditory perception, as stipulated in ISO 1996–2: 2017 requirements [23–25]. The measurements were taken at multiple points per campus including dormitory entrance, roadways, lecture theatre entrances, and cafeteria, during periods of peak activity. These measurements were taken over ten minutes intervals (LAeq, 10 min) to accommodate temporal fluctuations, during weekly sessions in May and February when Vimbwete uses is most prevalent. ArcGIS Pro was employed to generate noise maps by analysing sound level fluctuation for different campus areas like roads, parking areas, playgrounds, workshops, hostels, construction sites, cafeterias and classrooms entrances. Noise Mapping technique was purposely employed to represent noise levels for each campus in the form of colour contour to specify noise intensity as recommended by previous studies [22, 26].

2.3 Cognitive performance test

The study used a stratified random sample of 80 students of 18 to 24 years with a balanced gender distribution to ensure generalizable results [27, 28] from various disciplines (engineering and social science) to avoid oversimplification [29] while ensuring comprehensive results. The four universities encompass a diverse range of academic disciplines, spanning from the rigor of engineering, classified as a hard science, to the more interpretive nature of social sciences. In this context, students were evaluated under comparable spatial conditions, taking into account their unique learning experiences across these varying fields of study [30]. The sample size was determined through the application of the appropriate statistical formula as shown in Eq. 1 below [31] to ensure adequate representation of the population across four campuses.

$$t = \frac{\mathrm{M}}{\mathrm{SD}/\sqrt{\mathrm{n}}} \tag{1}$$

M is the Mean difference between paired observations (50 dB(A)—75 dB(A)), n is the Sample size and SD is the Standard Deviation for the variability of paired differences in reading time among individual participants to convey consistency of noise-induced delay.

Cognitive performance was assessed with two primary measures to examine the impact of noise on academic tasks as double-metric approach [32], including task efficiency, as the time taken (in seconds) to read a standard 197 -word passage, and task accuracy, as the ratio of correct responses to five comprehension quizzes. Both measures were contrasted between quiet (50 dB(A)) and noisy (75 dB(A)) conditions using a paired t-test. Noise exceeding 50 dB(A) was considered disruptive to intellectual activities requiring concentration, while the 75 dB(A) threshold was selected based on WHO guidelines and cognitive load theory, which explains noise-induced stress as being caused by an impaired working memory [33]. The 50 dB(A) and 75 dB(A) levels were obtained within the naturally occurring time periods under varying noise conditions with changes of about ± 4 dB(A) for low and peak hours respectively. The two noise levels were employed to measure the effect of campus noise on reading comprehension in situations with moderate versus high cognitive load for short-term exposures [34] in academic outdoor environments. The selection of reading speed as a measure, captures processing efficiency and attention while comprehension accuracy conveys working memory load under acoustic stress.

3 Results

The study's findings detail the spatial distribution of primary noise sources across the four university campuses in relation to designated outdoor study zones enhancing the understanding of the campus's acoustic environment. The research encompasses assessments of students' cognitive performance under varying noise conditions with the objective of quantifying decibel levels in different areas, collecting students' subjective feedback on noise and simulating acoustic intensity across multiple locations.

3.1 Campus physical environmental characteristics

The analysis reveals that campus noise from roads, railways, construction sites, and parking facilities significantly affect the environment. Many *vimbwete* (private study areas) are located near high-noise zones like lecture hall doorways, parking areas, playgrounds and busy streets, indicating poor spatial planning. The study spaces seem to be increasing due to student initiatives rather than strategic planning raising concerns about their effectiveness in meeting academic needs.

The spatial configurations of the campuses are notably porous, facilitating various forms of mobility that ultimately diminish quiet zones while increasing ambient traffic noise. Among the four campuses studied including MUST, TIA and MU, three are currently engaged in ongoing construction both within their boundaries and in adjacent areas. Notably, MUST is implementing an extension that incorporates the *Vimbwete* features into its campus layout, distinguishing it from the other institutions examined. The four campuses revealed diverse layout characteristics with varying setups and locations of noise sources, as illustrated in Figs. 2, 3, 4, 5.

The investigation revealed an absence of a master plan for campus development across the four institutions. Frequent power interruptions have led to reliance on noisy standby generators contributing to significant noise pollution and disrupting the serene environment essential for academic activities [35].

Noise levels differed considerably by source and location across the four campuses. In MUST, construction sites registered sustained levels of 84.0 to 97.5 dB(A), whereas the car parks registered 80.85 dB(A). Roadside spots, like those at TIA, topped at 88.9 dB(A), which contrasted with more subdued courtyards (For example, 66.1 dB(A) in TEKU). MU playgrounds and social areas manifested mid-range levels of 75.0 to 90.0 dB(A), typical of combined noise sources. These results show systematic exceedances of WHO thresholds, especially in the environments of high-activity areas (refer to Figs. 6, 7, 8 and 9).

Ranges of measured noise (65.6–97.5 dB(A)) exceed WHO 2018 guidelines (55 dB(A)) for academic environment, compromising acoustic comfort. Prolonged exposure to noise levels greater than 75 dB(A) in learning environment may impact cognitive ability, while peaks greater than 85 dB(A) near construction sites or roads suggest risks for hearing stress and fatigue, underscoring the importance of noise mitigation in campus development planning.

3.2 Campuses noise levels

All four campuses exhibited elevated noise levels ranging from 65.6 dB(A) to 97.5 dB(A), significantly exceeding the World Health Organization's guideline of 55 dB(A) for external noise. While the WHO (2018) guideline refers

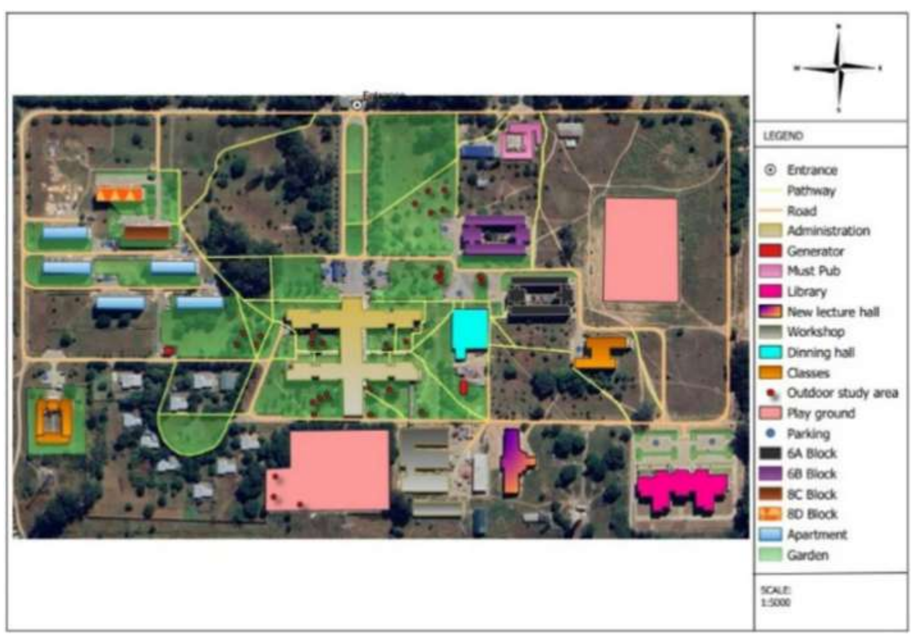

Fig. 2 Map of physical environmental characteristics at MUST campus

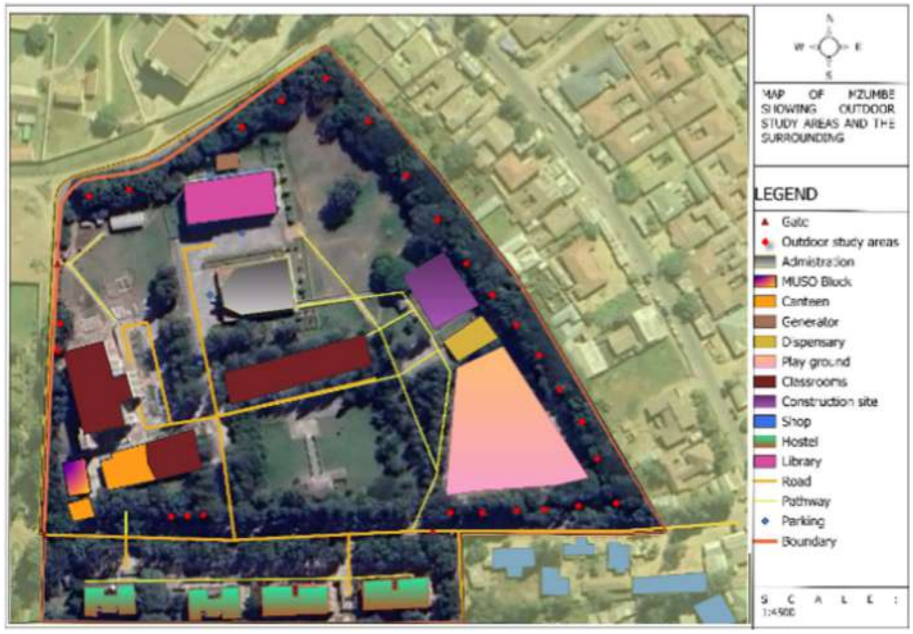

Fig. 3 Map of physical environmental characteristics at MU campus

Fig. 4 Map of physical environmental characteristics at TEKU campus

to a 24-h average, the study's transient measurements capture short-term noise peaks based on the WHO (2011) recognition of intermittent noise as a risk factor for cognitive impairment and reduced performance in an academic environment [36]. Specifically, noise measurements indicated that parking lots generated an average of 80.85 dB(A), while playgrounds and adjacent roadways recorded levels of 85.5 dB(A) and 88.9 dB(A) respectively. Noise mapping around the campuses further highlighted that approximately 70% of outdoor study areas are exposed to sound levels exceeding 65.0 dB(A), refer to Fig. 10.

Elevated noise levels on campuses like TEKU, TIA and MU are primarily due to vehicular traffic and student activities. The proximity to busy roads creates a constant background noise intensified by the movement of students to and from lecture sessions and high usage of parking facilities near outdoor study areas. Pedestrian traffic and conversations among students further add to the noisy environment while organized sports events like basketball, football and volleyball contribute to the overall soundscape impacting the campus experience.

Fig. 5 Map of physical environmental characteristics at TIA campus

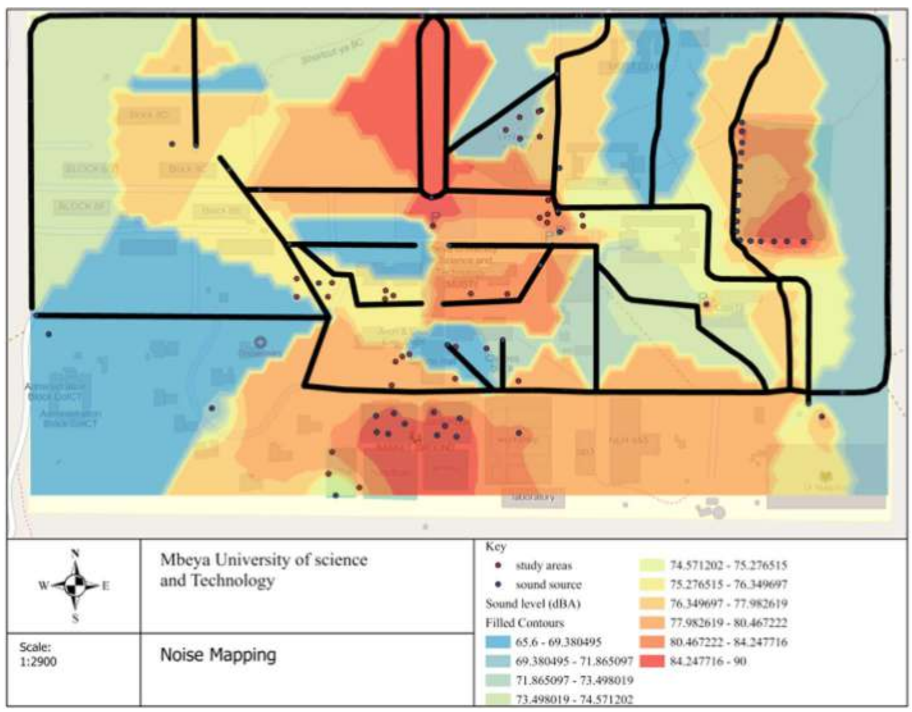

Fig. 6 Noise map and zoning at MUST campus

3.3 Students' cognitive performance

Two noise environments of reading comprehension tests produced different performance trends Fig. 11 and 12. Students needed a mean time of 64.3 s to finish the 197-word reading assignment in settings with about 50 dB(A) noise levels, earning an average score of 4 out of 5 accurate replies on comprehension questions. Mean reading time rose to 93.7 s while comprehension scores dropped to an average of 3 out of 5 when noise levels reached to about 75 dB(A). With MU exhibiting the biggest performance disparity (35.7 s increase) and TEKU displaying the smallest (27.4 s increase), these variations shown statistically significant variance across all four campuses ($p < 0.001$). The stability of these results across different institutions together with the preserved gender balance in sampling help to

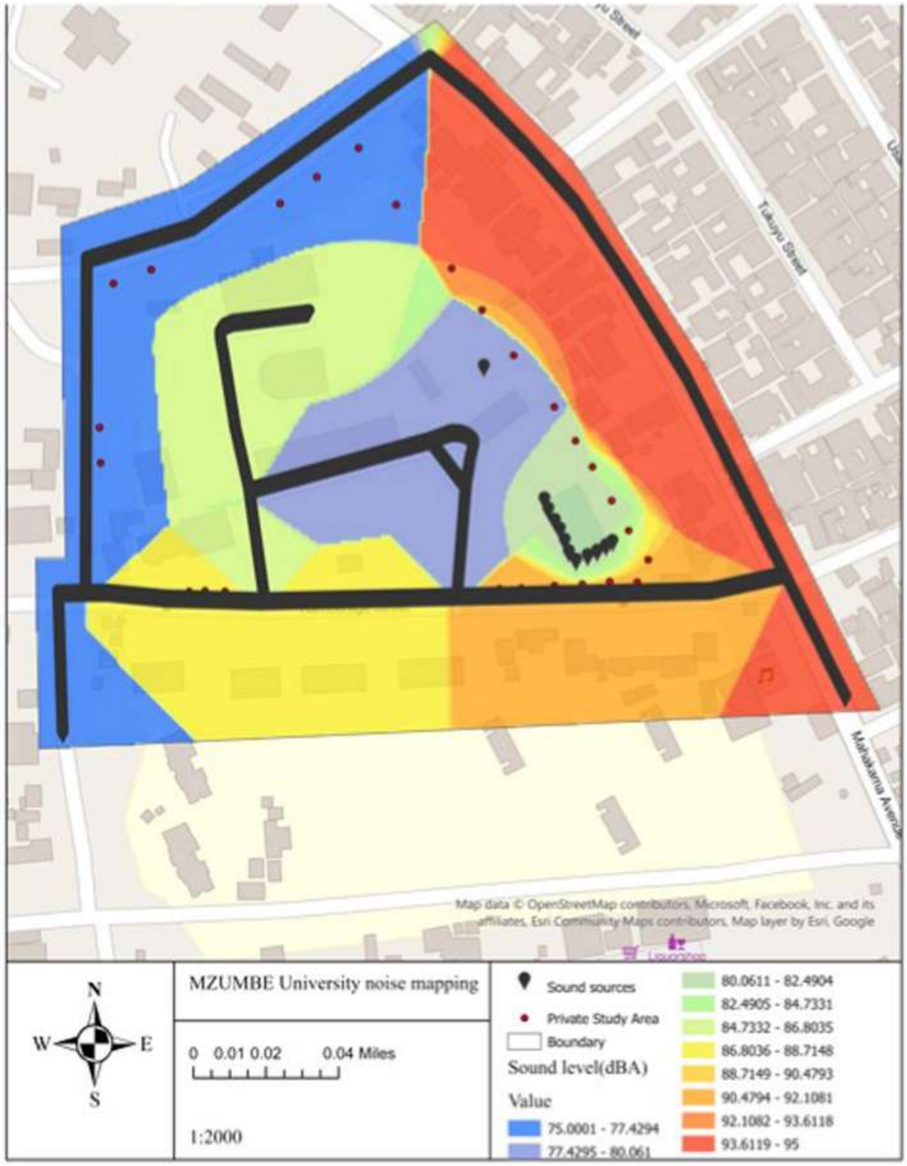

Fig. 7 Noise map and zoning at MU campus

confirm the dependability of the recorded relationship between noise level and students' performance as illustrated in Figs. 11 and 12 along with the data summarized in Table 1. Response latency was notably extended in the noisy environment suggesting an increased cognitive load. Rigorous statistical analysis corroborated the significance of these outcomes with a p-value of less than 0.05. Further details are documented in Table 1 and illustrated in Figs. 13 and 14.

4 Discussion

4.1 Impact of noise on students' cognitive performance

With reading times greatly rising from 64.3 to 93.7 s with a p-value of less than 0.001 and comprehension scores declining from 4 to 3 correct answers when noise levels grew from 50 dB(A) to 75 dB(A), the results show task-specific affects [37]. Although these reading-oriented results fit WHO concerns about intermittent noise, they should not be applied to all cognitive domains. Unlike WHO's 24-h average guidelines [36], the recorded highest level of 97.5 dB(A) around building

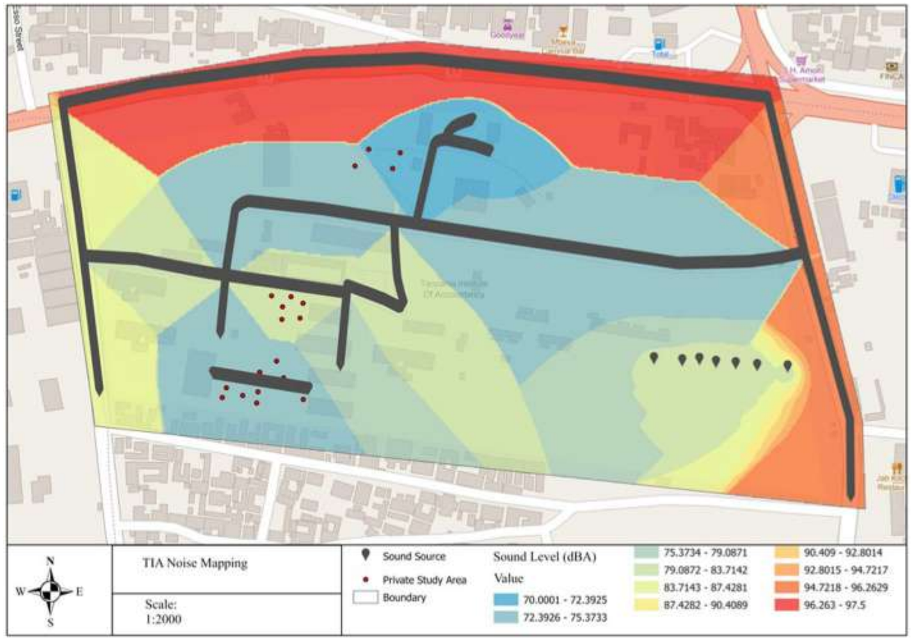

Fig. 8 Noise map and zoning at TIA campus

sites [38–41] reflect acute rather than chronic exposures. These results particularly point to weaknesses in outdoor reading activities rather than total cognitive decline.

4.2 Implications for campus planning

The absence of *vimbwete* integration in university master plans highlights the critical need for outdoor acoustic management strategies. Outdoor study environments become significantly less effective when situated near high-noise areas such as busy roadways or ongoing construction activities. Strategically relocating these study spaces to quieter zones within the campus would enhance the acoustic quality of the environment thereby fostering better concentration and minimizing noise-related distractions for students [42]. To minimize challenges associated to relocations, including spatial constraints, logistics of redesigning, and the cost associated, the implementation should consider phased strategies and stakeholders engagement. The use of strategic acoustic barriers and vegetative buffers like shrubs and trees can effectively reduce noise pollution on university campuses creating a better environment for students studying outdoors. Prioritizing these measures in master planning enhances the overall student experience and promotes both physical and mental well-being. Improved outdoor settings can reduce stress, boost learning and improve social adaptability contributing to a supportive campus atmosphere. Incorporating natural elements into outdoor study areas has proven to benefit mental acuity and cognitive development [43, 44].

Cognitive performance in humans is significantly impaired by extraneous noise which disrupts the surrounding environment. Previous research indicates that when noise levels exceed 95 dBA there is a marked reduction in auditory attention and an increase in mental workload [45]. This research indicates a notable decline in students' reading abilities shown by the increased time needed to read a 197-word paragraph. In quiet settings, the average reading time is 64.3 s which rises to 93.7 s in noisy conditions. Previous studies suggest that young adults generally take about 60 s to read a 200–300-word paragraph. In environments with around 75 dB(A) noise levels, participants took an average of 93.7 s for the reading task [46]. In conditions with ambient noise levels approximating 75 dB(A), the study found that it took participants an average of 93.7 s to read a paragraph consisting of 197 words.

4.3 Limitations

Interpreting these results requires some consideration of certain constraints. The study gauged noise level at moments of maximum activity as stipulated in Sect. 3.2 offering crucial information regarding worst-case situations but does not include cumulative effects of extended exposure. This is due to the fact, students use these areas for short period to supplement indoor class session. Also, although the sample size (n = 80) was sufficient to find statistically significant

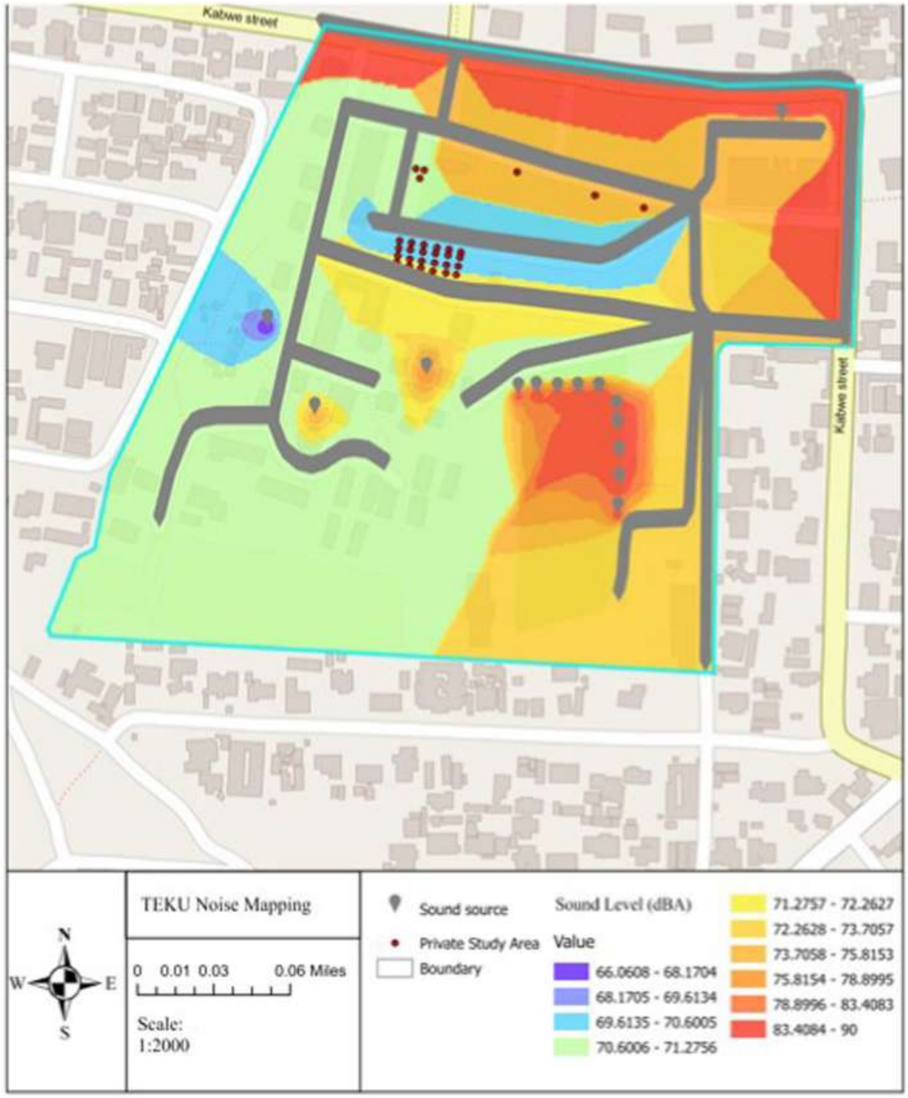

Fig. 9 Noise map and zoning at TEKU campus

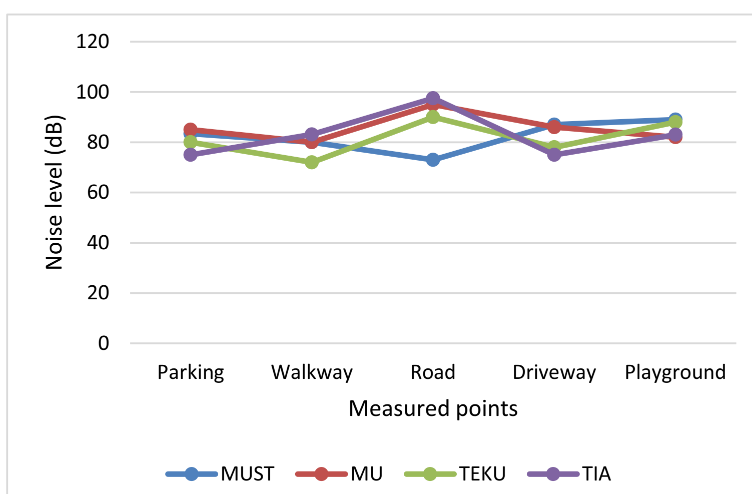

Fig. 10 Measured sound level at different location across four campuses

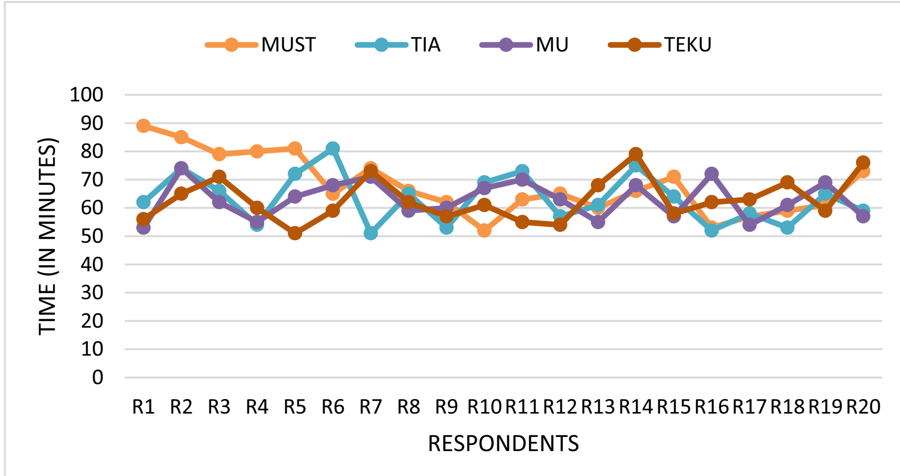

Fig. 11 Time taken by respondents to read a paragraph in sound level at ~ 50 dB(**A**)

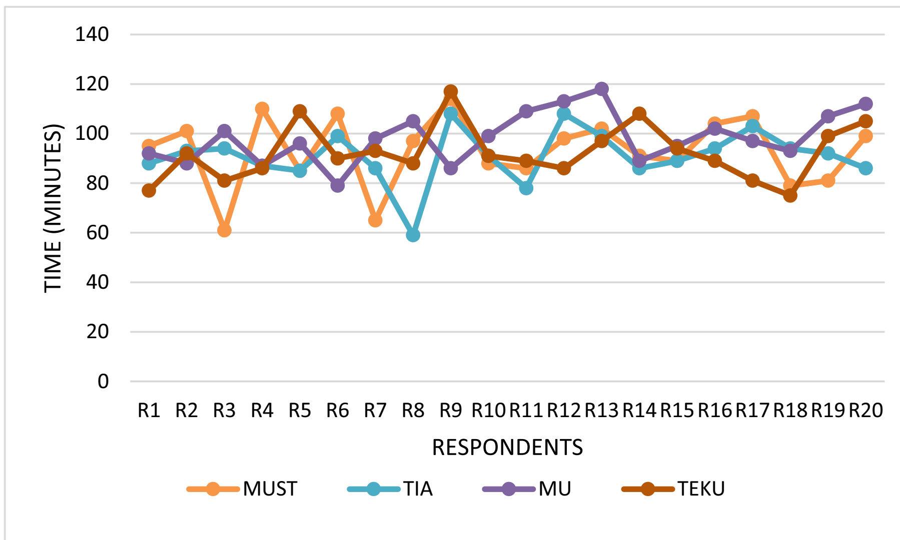

Fig. 12 Time taken by respondents to read a paragraph in sound level at ~ 75 dB(**A**)

Table 1 Paired t-test Results for reading times at 75 dB (A) as compared to 50 dB(A) environment

Campus	Mean at 75 dB(A)	Mean at 50 dB(A)	Difference	t- Value	p- value
TEKU	94.7	63.1	31.6	11.9	< 0.001
TIA	91.3	63.3	28.0	11.5	< 0.001
MUST	94.2	66.8	27.4	10.7	< 0.001
MU	99.4	63.7	35.7	13.1	< 0.001

effects as explained in Sect. 2.3, it might restrict generalizability to other demographic groups or institutional settings. Furthermore, the emphasis on reading comprehension tasks stated in Sect. 4.1 suggests these results might not generalize to other cognitive activities including creative work or problem-solving. The pragmatic limitations limited control over all environmental variables that can affect cognitive performance as well as noise levels. Through longitudinal designs and more thorough environmental monitoring, future studies could overcome these restrictions.

4.4 Strategies to improve the vimbwete performance

In order to enhance the Vimbwete performance, the study suggests two ways of enhancing functionality that comprise immediate noise reduction strategies for existing campuses and comprehensive mitigation for future campus development.

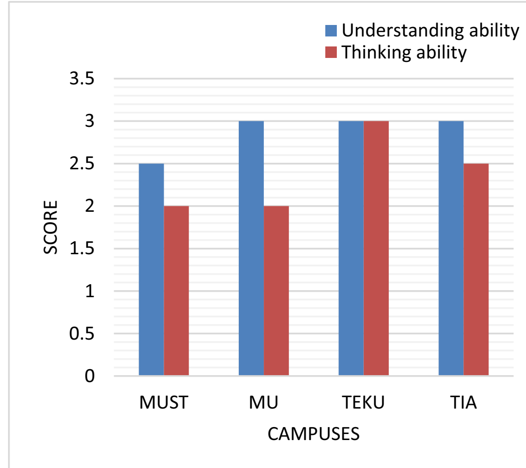

Fig. 13 Average scores by students when answer questions from the paragraph at sound level of ~ 75 dB(**A**)

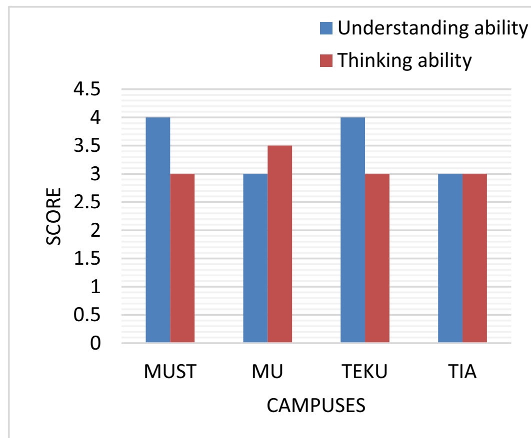

Fig. 14 Average scores by students when answer questions from the paragraph at sound level of ~ 50 dB(**A**)

4.5 Noise reduction strategies for current campuses

In order to effectively treat noise pollution in existing campus environments, the study recommends the use of three cost-effective, low-tech measures that are quick to implement for low economy institutions as adapted from evidence-based interventions on traffic noise reduction [22] and green buffer effectiveness [47, 48]. These include, installing modular acoustic barriers on high-traffic perimeters using prefabricated sound-absorbing panels that can reduce noise levels by 5 to 10 dB(A); enhancing existing green spaces by systematically introducing noise-reducing shrubs and foliage into existing planters and underutilized areas; and introducing temporary quiet areas in high-use outdoor study areas through the application of mobile partitioning and screens. These interventions can be implemented without structural modification and yield measurable noise reduction.

4.6 Noise mitigation for future campus development

To develop new campus project on design and construction, the study suggests the incorporation of more effective and comprehensive solutions for noise control from early stages of the planning processes. It includes landscape-based acoustic design where earth berms, water features, and sound absorptive hardscapes properly combined to produce natural noise barriers. The study further, recommends the use of zoned acoustic planning in which buildings, open spaces, and vegetations are strategically located so that campus soundscapes are optimized across campus. For future campus development, the use of construction materials for strategic barriers which are more advanced like porous concrete and micro-perforated panels can also provide inherent noise reduction. These future-oriented strategies supplement the initial designs by incorporating computational noise modelling techniques [22] and sustainable design strategies to ensure effectiveness for long-term. These recommendations are carefully designed to balance environmental issues with academic performance, creating noise control solutions to prove robust in the future as campuses grow and evolve. By incorporating these measures at the initial stages of campus development can create conducive outdoor learning environment.

5 Conclusion

The increased reading times of 93.7 s and 64.3 s at 50 dB(A) and decreased accuracy 3/5 and 4/5 correct answers shows that elevated noise levels (75 dB(A)) in outdoor study settings significantly degrade performance on reading comprehension assessments. For all four campuses, these effects were consistent noticed near high-noise zones including building construction sites registering noise level of 97.5 dB(A).

The results indicate that noise reduction techniques could significantly raise student performance for outdoor areas frequently used for reading-intensive study (for example during exams preparations). Particularly in areas with noise levels above 75 dB(A), the three suggested interventions including modular acoustic barriers, improved vegetation buffers, and temporary quiet zones to offer sensible alternatives for current campuses. Their efficiency might change, nevertheless, depending on certain campus designs and noise sources.

Integrating acoustic issues into master planning seems appropriate for future campus development, particularly for outdoor areas set for focused study. It should be considered that the results of this research on reading activities under noise exposure (short-term) particularly support these recommendations. Establishing ideal acoustic circumstances for other outdoor academic activities or long-term study sessions would need further investigation.

These findings highlight the specific difficulties of outdoor study environments in tropical university campuses and coincide with WHO's alarm over intermittent noise effects on concentration [36]. This emphasizes the requirement of context-specific acoustic planning that provides balance between academic needs and environmental conditions.

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Author contributions Buberwa Mukyamo Tibesigwa: Conceptualization, methodology, formal analysis, investigation, data curation, writing—original draft preparation, writing-review and editing.

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Data availability Further data used to this study can be available from the corresponding author on request.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate The research was approved by the Mbeya University of Science and Technology Research Ethics Committee (REC). The study considered all ethical consideration to all participants involved in interviews and orally consented to take part in the study. Assurance of confidentiality was granted to all participants prior to taking part in the study.

Consent for publication The author and participants consent this manuscript to be published.

Competing interests The authors declare no competing interests.

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